Service life estimation of heritage buildings: a case study

Silverio Hernández-Moreno
Department of Architecture
Universidad Autónoma del Estado de México, Toluca, Estado de México, México

Marcos Mejía-López
Department of Architecture
Universidad Autónoma del Estado de México, Toluca, Estado de México, México

Ignacio Mendiola Germán
Department of Architecture
Universidad Autónoma del Estado de México, Toluca, Estado de México, México

René L. Sánchez Vertiz-Ruiz
Department of Architecture
Universidad Autónoma del Estado de México, Toluca, Estado de México, México

Abstract- The goal of this document is to present a case study to estimate the service life of a heritage building in a quick and practical manner. The methodology is mainly a modification of the ISO 15686 factor method. The main result is a practical method to be used mainly by architects and restorers to produce residual service life estimations of historical buildings taking into consideration not only the 7 typical ISO durability factors, but also one more related to the degree and quality of redevelopments and reparations carried out on the building. It is concluded that it is a practical and versatile method to estimate not only the service life of historical buildings but also any sort of building for which remaining service life is needed and even to estimate architectural projects' service life.

Keywords– Built heritage, Residual service life, Durability, ISO 15686.

I. Introduction

Most of the buildings presently in the world are about to reach the service life for which they were designed and built, and a serious problem detected is that they have not had mayor refurbishment, neither has it been fully considered re-planning their service life, because of this it is important to have statistical data in this regard in order to be able to plan buildings as well as redesign and design entire cities and their infrastructure and equipment for the future

In the practice of conservation of buildings and sustainable architectural design in many architecture firms around the world, it has been identified that frequently no attention is paid to the project's service life plan and design, in the case of a new building, and in the case of mayor or significant refurbishment, no attention has been paid to the calculation of the buildings' remaining service life or service life adjustment.

Service life understood as the period after the installation or construction over which the building or its parts meet or exceed the performance requirements for which they were designed and built [1]. Therefore, at the end of service life there must be refurbishment and reparations, which implies extending the building's service life.

There is a condition in service life planning and durable design; it states that if at the moment of calculating the service life of a project, this is not the same as or does not surpass the expected service life, then the project cannot go on to executive design, much less to construction; so there is need to return to the stage of predesign or pre-project so as to design on the basis of the durability of construction components and other factors, listed below [1]:

- Quality of materials and construction components,
- Quality of integral design (architectural and constructive),
- Quality of the construction workforce,
- Indoor climate,
- Outdoor climate,
- Operating conditions of the building,
- Degree and level of maintenance.

Durability understood as the capability that a building or a component have to reach the optimal performance of their functions in a determinate environment or site, for a determinate time with no need for corrective maintenance nor significant repairs [2].

To ascertain service life there are several methods, being the following distinguishable:

- Statistical methods, for example, the historical registration method only for buildings in similar conditions [3].
- Engineering methods, such as mathematical simulation and physical tests methods such as "accelerated aging" that are very useful for very specific cases of materials and construction components, which in addition to be very expensive, need experts to be executed [4].
- Factor methods such as ISO 15686, which are more friendly with the architect's experience, though limited to the planner's experience [5].

Service life prediction for buildings and their components is not a hard science, but only approximations to numerical values of what we may expect from the buildings' service life durability [6], even mathematic and statistical methods are only approximations, and the factor method by ISO 15686 is an approximative and qualitative method, subjective to a certain extent.

The goal of the present document is to present a case study in order to estimate the remaining service life of a building in a quick, practical and approximative manner applying a factor method based both on ISO 15686 [1] and Hernández's service life estimation method [5], so as to record service life information of heritage buildings, in this case the historical building *Capilla del Señor del Calvario* [Chapel of the Lord of the Golgotha], in Toluca, State of Mexico, from the architect's standpoint without resorting to mathematical or engineering methods, or accelerated aging tests, which is very expensive and time-consuming.

II. LITERATURE REVIEW

It is known that service life prediction for buildings and their components is not a hard science as noted above, though the idea is to approach as much as possible to be able to have the most reliable information to design and construct the building and to keep it operational and in functions.

By and large, buildings' Life Cycle Assessments (LCA) use a design service life of about 50 years and have simplified descriptions of their operation and maintenance, so the typical service life is inappropriate for some materials considering their exposure and use, and the simplified descriptions do not fully account for maintenance, reparation and replacement cycles [7].

In the case of existing buildings, which have been already used for some time, they may fall into two hypothetical cases:

1. Existing buildings that have not reached their service life end.
2. Existing buildings that have already met their initial service life, but which have had one or more redevelopments or major repairs owing to which they are still functioning.

In the particular case of the estimation of the service life of existing buildings, what is intended is to find out their remaining service life and durability over such remaining time, with a view to keeping them in optimal conditions for the use they were originally designed or later redesigned.

A study by [8] on abandoned reinforced concrete buildings which were assessed owing to salt deposits on the surface (efflorescence), carbonation, crack formation and corrosion in rebars; however, at small-scale the structure was assessed to detect degradations in performance by means of destructive and non-destructive tests, steel tensile strength tests and corrosion tests; finally, it was concluded that according to the exposure conditions of the environment, an abandoned reinforced concrete building, as in the case above, might not carry out the designed resistance functions after a 12-year period in this case. In such study, the analysis method supported on an indicator of the construction components' depreciation and on physical and chemical properties' degradation variables of the studied construction components.

For the case of reinforced concrete structures, which is a staple in construction industry, a study by [9] mentions that owing to everyday use and environmental effects, the structure gradually deteriorates so the actual residual life at some point needs to be adjusted as regards the structure's service life, according to the observance of essential requirements of structural integrity and safety, and from mechanical strengths as well as service conditions.

Such article has as an objective to develop a rigorous methodology to estimate the remaining service life of a reinforced concrete structure from seismic and wind considerations, on the basis of the structure's current condition, which comprises the residual material's resistance and the residual strength of sectional areas [9]. Their methodology is followed by an illustrative example and a parametric study that involves a 10-storey reinforced concrete construction frame, bearing loads of wind and earthquakes; influences from several parameters such as concrete resistance and the residual area of the rebar on the expected residual service life are studied. The proposed methodology offers a simple estimation, though rational, of residual service life for reinforced concrete (Dhawan et Al., 2019).

A study by [10] presents two methodologies to assess the functional service life and protection level of cultural heritage in Chile. This research intends to establish a correlation between the functional performance of heritage buildings and the Chilean code regarding the definition of preservation of historical heritage buildings. A multiple linear analysis regression is applied to define the level of protection according to the Chilean standard, in the index of functionality of constructions of the wood industry heritage [10].

Another study on the buildings' service life in terms of functionality presents a complex analysis that establishes a new expert system based on fuzzy logic to forecast the buildings' service life. The system developed has the intention to manage vulnerabilities and risk variables that affect the performance of a building. These parameters are involved in the process of administration and management of the building and indicate durability in terms of service as a parameter of the exit model [11].

Studies such as that by [12] developed an expert system to predict the service life of buildings in an computing application that contributes to preventive conservation of architectural heritage mainly based on ISO 31000 (Risk Management Systems) and on a new expert system that predicts the future service life of homogenous heritage sites in all the world by means of an inference motor based on fuzzy logic.

A study related to road construction presents, firstly, the conditions of the state of conservation of the road by means of a paving condition index, while deflection data are obtained by means of measurements carried out with a deflectometer, so in the end, by means of a regression model and using the correlation between the paving condition index and flection data, the remaining service life is ascertained [13]. This way, it is noticed that it is an engineering method based on mathematical and statistical models, basically linear regression.

A study by [14] describes a method to assess the service life of façades planned with a number of materials applying statistical tools; using multiple linear regression analysis mathematical models to estimate the degradation of this sort of coating. Which is also a statistical and mathematic method of engineering use.

Another different study and using accelerated aging tests on construction materials had as a main goal to define the theoretical case that supports the accelerated tests' measurements and the connection between aging and bituminous sheets' service life. *Arrhenius* equation for accelerated tests was used as a theoretical support for experimental tests of bituminous sheets at high temperature and various exposure times [15]. As it is known, accelerated aging tests of construction materials are very expensive, they relatively take a lot of time and it is limited to certain materials and building components.

In recent decades, a number of industries established at large scale have been perfecting the approaches to estimate the service life of polymer-based materials and products [16]. Cutting-edge methodologies are based on open-air and laboratory accelerated aging techniques which combine stress factors in a similar manner to that observed in the end use environment, though at enhanced levels [16].

Furthermore, and on the subsistence of old constructions, [17] points out:

"Failures are due, on the one side, to the deterioration experienced by the structural properties over time, and on the other, the longer a construction's life is the more intense the phenomena that may affect it. Related to the belief above, it is the one that supposes that a building's lengthy existence is sufficient proof that its security is adequate. This belief is also associated to the opinion that there is no need for security checks for an old building and that the evidence of its presence is enough" [17].

"On occasion, however, there is no external evidence of the progressive loss of resistance of a structure, existing cases of sudden collapses of buildings with no signs of damage" [17].

"By and large, visual supervision is not enough, then it is convenient to utilize refined techniques of supervision and monitoring. A quantification of security is necessary, on the basis of finding out the structural properties and analysis methods concurrent with the structure's actual behavior" [17].

The architects, urban planners and developers of cities and buildings have a series of tools to design, planning, maintain and build architectural and urban infrastructure using sustainability criteria [18]; making durability design in buildings is one of these useful tools.

After revising the afore cited literature, it is found that most are examples of service life predictions and calculations for remaining or residual service life based on mathematical, simulation, accelerated aging and statistical methods of engineering nature that frequently are not part of the architect's profile. This way, it is proposed to use a proper method based on ISO 15686 factor model, which is a quick reliable method to qualitatively estimate the service life of any building from the standpoint of the architect, and mainly to have information prior to planning or re-planning the durability of existing buildings.

III. METHODOLOGY

1. **Definition of the object of study:** at this point the building under study must be described both architecturally and constructively.

2. **Definition of the study variables:**

As a response or dependent variable:

Estimated Service Life (ESL). It is the service life to be found out, which is an adjusted value of reference or design service life. In this case, such ESL will be the building's remaining service life in the end.

As independent or control variables:

a) Reference Service Life (RSL) according to ISO 15686 for permanent buildings such as: museums, temples, general archives, central libraries, etc. [1].

b) the durability and deterioration factors:

F1) Quality of materials and construction components,

F2) Integral design quality (architectural and constructive),

F3) Construction workforce quality,

F4) Indoor climate,

F5) Outdoor climate,

F6) Building's operating conditions,

F7) Degree and level of maintenance,

F8) Degree and quality in refurbishing and reparations carried out.

The authors of the present document propose an eighth factor (F8), related to the refurbishment in the building, measured with the same criterion (table 1) as the other 7, and according to the number and quality of significant interventions (refurbishing and reparations), which will be described in detail in Results.

3. **Define the method to follow to calculate ESL**

The formula (1) will be utilized in the estimation of ESL (ISO, 2011):

$$ESL = RSL\,(F1)\,(F2)\,(F3)\,(F4)\,(F5)\,(F6)\,(F7)\,(F8) \qquad (1)$$

The assignation of the factor values for the estimation is carried out according to table 1:

Table 1. Assignation of service life factors and durability of buildings

Does not meet	Meets	Meets over expectations
0.80	1.00	1.10

Source: [1]

Factors F1 to F8 will be assigned according to table 2, which is information based on [1] and on [5].

Table 2. Format to assign and determinate factors that affect a project's durability

Building's current state	Assigned value
F1. Technical description of the conservation state of the quality of materials and construction components.	¿?
F2. General technical description of the level of architectural-constructive design.	¿?
F3. Description of the workforce quality and level.	¿?
F4. Qualitative and quantitative description of the building's indoor environmental conditions.	¿?
F5. Qualitative and quantitative description of the building's outdoor environmental conditions.	¿?
F6. Description of the use and operability of the building.	¿?
F7. Description of the degree and level of maintenance.	¿?
F8. Description of the degree and quality of refurbishment and reparations made to the building.	¿?
Building's service life estimation	
1. Technical norm: ISO 15686	
2. Factor method formula: *ESL = RSL (F1) (F2) (F3) (F4) (F5) (F6) (F7) (F8)*	
3. Entire building's estimated (years)=	¿?

Sources: [1, 5]

IV. RESULTS

Definition of the object of study

It is the historical and heritage building called "Chapel of the Lord of the Golgotha" in Toluca, State of Mexico, a neoclassical sort of building erected in 1850 upon a pre-Columbian archeological zone. It comprises two naves, the first and main was a barrel vault of masonry of tezontle and lime-sand mortar, which was recently replaced (year 2000) with a reinforced concrete slab reinforced with IPR beams: the main entrance has an arch that frames the access to the building and a window to the choir in the upper part. To frame the bells, the façade has a small bell-gable with three openings (figure 1). The chapel's main construction material is made of volcanic stone fixed using lime mortar. The building has a basement, a ground floor and a first level that is a choir. The finishes, both coats and paints are lime-based. The second nave has been recently attached and has a contemporary construction that holds the priest's house, reason why this nave was excluded from the remaining service life estimation, since what is intended to find out is only the chapel's remaining service life.

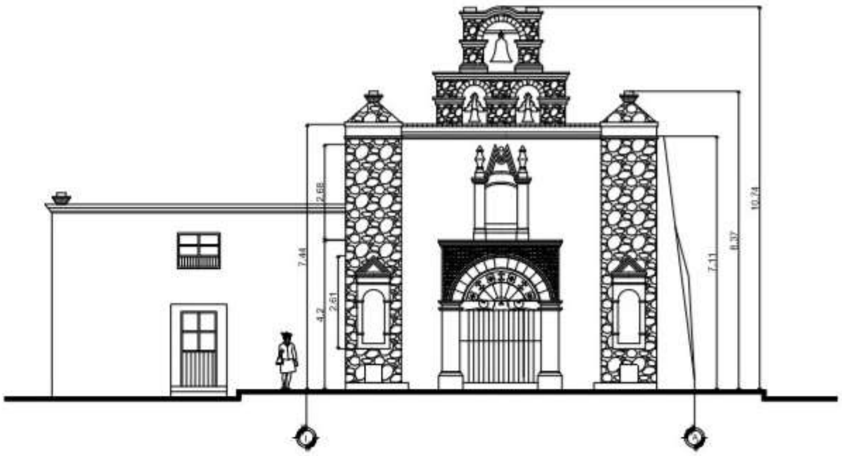

Figure 1. Main façade (north) of the “Chapel of the Lord of the Golgotha” in Toluca, Mexico (Drawing by: Architect Gabriela Sánchez Zavala, 2019).

Determination of independent variables and service life estimation

Reference service life = 100 years for permanent buildings according to [1]

Service life factors or building’s durability = Assigned in the second column of table 3.

The following results refer to the execution of the case study, referred in Methodology, and presented in table 3.

Table 3. Example of the estimation of remaining service life of the building of the study case

Current state of the building	**Assigned value**
F1. Technical description of the conservation state of the quality of materials and construction components: It is traditional construction of the mid XVIII century of volcanic stone masonry with walls and buttresses. Since the building has had various recent interventions and one of them, in the year 2000, demolished the original roof made with a tezontle barrel vault with another of reinforced concrete, this has compensated the distributions of the structural loads causing severe problems which up to the present have not been solved. In addition to this poor intervention, maintenance over the last 20 years has not been suitable and virtually inexistent during the last 10 years, as there are no records of maintenance or interventions since 2008.	0.80
F2. General technical description of the level of architectural-constructive design: Although the original design is considered adequate, the most recent interventions evince that redesign has not been very favorable for restoration and maintenance works.	0.80
F3. Description of the workforce quality and level: The quality of the workforce in time and of all the interventions the building has had are considered acceptable, so this factor must neither affect negatively nor positively on the estimation of remaining service life.	1.00
F4. Qualitative and quantitative description of the building’s indoor environmental conditions: In the city of Toluca, the issue of the weather, both indoors and outdoors, does not have significant repercussions on the buildings’ deterioration, as it is not extreme, however, since maintenance conditions are bad, the building retains moisture in some construction elements that would be undermining its remaining service life	0.80
F5. Qualitative and quantitative description of the building’s outdoor environmental conditions: In the city of Toluca, the issue of the weather, both indoors and outdoors, does not have significant repercussions on the buildings’ deterioration, as it is not extreme, however, high radiation conditions from the city’s altitude, frequently affect finishes in roofs and ceilings.	1.00
F6. Description of the use and operability of the building: Operation and use conditions of the building neither directly nor significantly affect the building.	1.00
F7. Description of the degree and level of maintenance: Owing to the conditions found in the building’s diagnose and owing to the detailed review of the records in National Institute of Anthropology and History on the building it was found that maintenance was poor in quality.	0.80
F8. Description of the degree and quality of refurbishment and reparations made to the building: Owing to the conditions found in the building’s diagnose and owing to the detailed review of the records in National Institute of Anthropology and History on the building, it was found that interventions and restorations were poor in quality.	0.80
Estimation of the building’s service life:	
1. Technical norm: ISO 15686	

2. Substitution of previously assigned in the factor method formula: *ESL= 100 x 0.80 x 0.80 x 1.0 x 0.80 x 1.0 x 1.0 x 0.80 x 0.80*	
3. Estimated service life of the entire building (years):	32.76

Sources: [1, 5]

At the end of table 3 it is noticed that the remaining service life for this case study is barely 32.76 years, since factors F1, F2, F4, F7 and F8 affect to a large extent the reference service life. To begin with, the building is not in optimal conditions, but if an adequate intervention is not carried out in the following years, the building will deteriorate exponentially, mainly owing to structural reasons that affect all the construction components.

V. CONCLUSIONS

As regards the method it is concluded that it is a practical proposal that facilitates and helps in an efficient and quick manner to find out service life, in this case remaining, in existing buildings, nevertheless the method can be applied to new constructions or at project level.

The method proposed, in spite of depending to a large extent on the designer's experience, planner or in this case the restorer, is a reliable method to estimate the service life of buildings and widely accessible for most of the architects and restorers. Owing to these characteristics, the method is still qualitative method with reliable though subjective information dependent on the experience of the designers or planners.

Regarding the results of the study case, it is concluded that:

- The remaining service life for the study case was considered much affected in a negatively way by most of the factors (in this case 5 out of 8), since the current conditions of the building turned out in very bad conditions, and since virtually there is no action plan for the rescue and preservation of the building.
- The records of National Institute of Anthropology and History for the case of this building state that there has not been any intervention since 2008, so a preservation and maintenance plan is necessary for this building considered historical heritage.
- Despite a long reference service or design life was considered in the calculation of the remaining service life estimation of the building; it considerably decreased from 100 to 32.76 years, which means that most of the durability factors influence on its deterioration and consequentially short remaining service life.
- In this case, the factors that affected the most the remaining service life of the building under study were: (F1) the state of preservation of the materials and construction components ; (F2) the level of architectural and constructive re-design; (F4) the building's indoor environmental conditions; (F7) the degree or level of maintenance of the building; and, (F8) the degree or level of interventions, mainly because of the record of the intervention in 2000.

REFERENCES

[1] ISO (2011), ISO 15686-1:2011: *Buildings and constructed assets -- service life planning -- part 1: general principles and framework*, ISO, Switzerland.

[2] Canadian Standards Association (2001), *S478-95 (r2001): Guideline on Durability in Buildings*. CSA, Canada.

[3] Sjöström, C., Jernberg, P. (2010), "International standards for design life of constructed assets". In: CIB World Building Congress, paper 192, (pp. 1-6), (CIB). Wellington, New Zealand. Bruno Daniotti and Fulvio Cecconi (Ed.). CIB W080: Test Methods for Service life Prediction. Rotterdam (pp. 1-6), CIB Publication, The Netherlands. http://site.cibworld.nl/dl/publications/w080_wg3_report.pdf

[4] Hovde, P.J., Moser, K. (2004), "Performance based methods for service life prediction, work presented" at: W080 Prediction of Service Life of Building Materials and Components (Joint CIBRILEM 2/3 Commission), International Council for Research and Innovation in Building and Construction and Swiss Federal Laboratories for Materials Testing and Research Laboratory for Concrete and Construction Chemistry (RILEM), Rotterdam, The Netherlands.

[5] Hernández Moreno, S., Servín Cárdenas, P. Ocampo Lugo, D. G. (2017), Comparative analysis method for service life estimation in architectural and durable design, *Entreciencias: diálogos en la Sociedad del Conocimiento*, 5 (12): 1-9. DOI: /10.21933/J.EDSC.2017.12.213

[6] Building Performance Group Limited (2001). *Building services component life manual*, United Kingdom: Blackwell Science.

[7] Grant, Aneurin and Ries Robert (2012), Impact of building service life models on life cycle assessment, *Building Research & Information*, 41 (2), 168-186. Retrieved from <http://dx.doi.org/10.1080/09613218.2012.730735>.

[8] Mohammad Ismail, Chan Kee Yew, Bala Muhammad (2016). Life-span prediction of abandoned reinforced concrete residential buildings, *Construction and Building Materials*, 112 (2016), pp. 1059-1065. https://doi.org/10.1016/j.conbuildmat.2016.03.012

[9] Dhawan, S. K., Bindal, A., Bhalla, S., & Bhattacharjee, B. (2019). Expected residual service life of reinforced concrete structures from current strength considerations. *Advances in Structural Engineering*, 22 (7), 1631–1643. https://doi.org/10.1177/1369433218818001

[10] Prieto, A. J., Vásquez, V., Silva, A., Horn, A., Alejandre, F. J., & Macías-Bernal, J. M. (2019). Protection value and functional service life of heritage timber buildings. *Building Research & Information*, 47(5), 567-584. doi:10.1080/09613218.2017.1404827

[11] Prieto, A. J., Macías-Bernal, J. M., Chávez, M., & Alejandre, F. J. (2017). Fuzzy modeling of the functional service life of architectural heritage buildings. *Journal of Performance of Constructed Facilities*, 31(5), 4017041. doi:10.1061/(ASCE)CF.1943-5509.0001021

[12] Prieto Ibáñez Andrés José, Macías Bernal Juan Manuel, Chávez de Diego María José, Alejandre Sánchez Francisco Javier (2016). Expert system for predicting buildings service life under ISO 31000 standard. Application in architectural heritage, *Journal of Cultural Heritage*, 18 (2016), pp. 209-218. https://doi.org/10.1016/j.culher.2015.10.006

[13] Setyawan Ary, Nainggolan Jolis, Budiarto Arif (2015). Predicting the Remaining Service Life of Road Using Pavement Condition Index, *Procedia Engineering*, 125 (2015), pp. 417-423. https://doi.org/10.1016/j.proeng.2015.11.108

[14] Silva A., Dias J.L., Gaspar P.L., de Brito J. (2013). Statistical models applied to service life prediction of rendered façades, *Automation in Construction*, 30 (2013), pp. 151-160. https://doi.org/10.1016/j.autcon.2012.11.028

[15] Kunič, R., Orel, B., & Krainer, A. (2011). Assessment of the impact of accelerated aging on the service life of bituminous waterproofing sheets. *Journal of Materials in Civil Engineering*, 23(12), 1746-1754. doi:10.1061/(ASCE)MT.1943-5533.0000326

[16] Haillant Olivier (2011). Accelerated weathering testing principles to estimate the service life of organic PV modules, *Solar Energy Materials and Solar Cells*, 95 (5), pp. 1284-1292. https://doi.org/10.1016/j.solmat.2010.08.033.

[17] Meli Piralla, Roberto (1998). *Ingeniería estructural de los edificios históricos*, Mexico: Fundación ICA.

[18] Hernández-Moreno, S. & Crúz-Medina, M. (2011). Sustainable management of domestic water residues and diminution of discharges into municipal collectors in Mexico. *Theoretical and Empirical Researches in Urban Management*, 6(2), 21-34. Retrieved from https://search.proquest.com/docview/868671627?accountid=189277